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III. *On the Longitude of the Armagh Observatory, given by fifteen Chronometers of Arnold and Dent, &c. By the* Rev. Dr. Robinson, M.R.I.A., &c.

Read 10th December, 1838.

THE determination of this important element is at least as difficult as essential; and whatever be the care of the astronomer it often happens that after years of observations have elapsed, the result still remains in some degree uncertain. The various methods of determining arcs of longitude have each their peculiar causes of error. When the methods of signals can be employed with only one intermediate station, it is decidedly the best; but obviously the measurement of large distances is in most cases impracticable, and when many stations intervene the accumulated errors may attain a serious magnitude. The expense of this process, and the number of assistants required, are also frequently very serious objections.

The longitudes assigned by geodetic operations depend on an assumed figure of the earth, whose constants are not well known, whose very existence is problematical; and even if correct, it will differ from the Astronomical longitude whenever local attractions deflect the direction of gravity to the east or west of the theoretic vertical.

The mere observation of an occultation is the most satisfactory that can be imagined in common cases; but there is uncertainty enough in deducing from it a longitude, caused by the doubtful nature of some elements that enter the calculation. It is affected by errors in the tabular place of the moon, which are not totally corrected when the declination has been actually observed, as only one limb can be taken, and that is affected by irradiation. It is influenced by the error of the tabular semidiameter, and still more of the horizontal parallax, which is to a certain extent hypothetical, whether given by theory or deduced from observation. And lastly, it depends on the assumed distance of the spectator from the earth's centre, a quantity computed on the hypotheses of its spheroidal figure and given compression, but which in strictness ought to be investigated by independent research.

In cases when the apparent tract of the star is very oblique to the moon's limb, its irregularities present a new source of error; and the final result is, that though the observations may be certain to a tenth of a second, the longitudes deduced may differ several seconds, and the truth can only be attained by a mean of many, taken under circumstances differing as much as possible.

The method of transits of the moon and lunar stars, though it afford an easy and pretty accurate approximation, is affected by the influence of irradiation, which I believe to vary not only with the telescope, but also with atmospheric changes. The *personal equation* is also different in some instances, for the planet and the stars, as I infer from the fact, that the transits observed by my late assistant gave the longitude five seconds of time less than those observed by myself after his death. In this method, therefore, it is necessary not merely to have observations of each limb, but to multiply the stations of comparison, that among the variety of observers and telescopes a kind of mean result may be obtained.

The determination by chronometers depends on the perfection of these machines, and in particular on their rate being unchanged by the agitation of a long journey. This, strictly speaking, is never the case, though it is sometimes very nearly accomplished, and its effect will disappear from the mean of the results obtained in going and returning, if the circumstances of the two journies are nearly similar.

Unfortunately it rarely happens that an astronomer has the power of making these experiments on a sufficient scale; but such an opportunity seemed to Sir William Hamilton and myself to present itself, in consequence of Mr. Dent's chronometric visit to Paris, and the yet more remarkable notice, read at the Newcastle Meeting of the British Association, of the Chronometric Longitude of Sir Thomas Brisbane's Observatory. Mr. Dent not merely promised us every assistance, but when, having obtained the consent of the authorities of our respective observatories, we proceeded to make the necessary pecuniary arrangements, he treated the matter as one of science, not of commerce, and not only took on himself the expense and risk of the journey, but came in person.

The chronometers which he placed at our disposal were fifteen, of which twelve were those that had been used in the determinations of Paris and

Makerstown. These latter were rated for some days at the Royal Observatory, Greenwich, and on September 20th were delivered to Mr. Dent. The remaining three were timed by the pupils of the Marine School at Greenwich, on the same day. They were packed in two boxes, and kept steady by a stuffing of horse hair, which to me at least appeared a very insufficient guard against the concussions of their rapid journey, but it seems to have been effectual. Much of this journey was performed with the marvellous rapidity of modern improvement, yet it may be questioned whether a slower passage would not have been more favourable; for the jarring of the railroad is severe, and the peculiar vibration of a steam-vessel I know to be very liable to disturb the performance of a chronometer. In this instance, of the total distance travelled, 275 miles were sea, 190 in Ireland in the common cars or stage-coaches, and the rest, amounting to 500, were performed on railways.

On the morning of September 22, the watches were compared at the Dublin Observatory, with the transit clock, by Sir William Hamilton, his assistant Mr. Thomson, and Mr. Dent himself; and on that of the following day, at Armagh, by Mr. Dent and myself. As Mr. Dent's time was precious, and I attach little or no importance to *stationary* rates, he started on the evening of the 24th, after we had again each compared the watches; and revisiting Dublin on the following day, and again making the comparisons, he sailed in the evening for Liverpool. The watches were finally returned to Greenwich, and compared by Mr. Main with the transit clock on the 27th, shortly after noon.

In making these comparisons, the Dublin astronomers appear to have taken beats of the watches, and divided the seconds of the sidereal clock. Mr. Dent took beats of the clock, and divided those of the watch, and I waited for coincidences and separation of the beats,—far the most accurate, but also far the most tedious mode of comparison. My results were, however, almost identical with Mr. Dent's.

Mr. Main, I believe, used the same method; for entire and half seconds only appear in his comparison, as must be the case when the watches beat twice in the second.

If we denote by E the correction of a watch when leaving the eastern, W that when arriving at the western station, I the interval of the watch's time between the two comparisons, and R its rate, (+ when losing, because it increases the positive correction,) we obviously have

$$L = E - W + R \times I,$$

and accenting the letters for the return,

$$L = E' - W' - R' \times I'.$$

If we suppose $R = R'$, that is, either the rate unchanged on the road, or similarly disturbed in the two journeys, then we have

$$R = \frac{(E' - W') - (E - W)}{I + I'} \qquad (1)$$

which may be called the *travelling rate*, and is given by subtracting from the watches' change between the two eastern comparisons the change between the two western, and dividing by the difference of the intervals; and this obviously is the rate which should be used.

We have also

$$2L = E' - W' + E - W + R \times (I - I') \qquad (2)$$

from which it is obvious, that if the times employed in going and returning are equal, or nearly equal, the effect of an error in the assumed rate is insensible in the mean of the two.

As the expression of R assumes that the longitudes obtained going and returning are equal, it is obvious that when the *travelling rate* is applied, it is useless to compute them separately.

If we suppose that $E - W$ requires a correction ϵ, whether caused by errors in the comparisons, or by accidental disturbance on the journey, then we obtain a value of R by eq. (1), which requires the correction

$$\rho = \frac{\epsilon' - \epsilon}{I + I'}$$

and the correction of the mean longitude given by eq. (2)

$$dL = \frac{\epsilon I' + \epsilon' I}{I + I'}$$

which in general will differ but little from that which occurs if we use stationary rates,

$$d\text{L}'' = \tfrac{1}{2}\epsilon + \tfrac{1}{2}\epsilon'$$

Errors caused by the journey produce opposite effects going and returning, and as the disturbances may be expected to be nearly equal in the two cases, it is highly probable that their effect on the mean longitude is insensible in such a case as the present.

Having premised so much as to the principles of the process, I annex its elements. The first column of the following table contains the number and distinguishing letter of the watch; the second its correction at the epoch of its own time given in the third; the fourth and fifth are for the return.

GREENWICH OBSERVATORY.

Arnold and Dent 1034	A	$+ 4^{m}.57^{s}.36$	$20^{d}.0799$	$+ 5^{m}.17^{s}.92$	$27^{d}.0278$
„ 1042	B	— 0.1.58	20.0847	+ 0.13.61	27.0218
„ 965	C	+ 3.11.15	20.0809	+ 3.24.89	27.0219
„ 910	D	+ 0.19.53	20.0014	+ 0.48.81	27.0271
„ 718	E	+ 3.32.60	20.0805	+ 3.44.14	27.0278
„ 1663	F	+ 0.9.33	20.0833	+ 0.30.81	27.0295
„ 1155	G	— 0.0.90	20.0833	— 0.18.76	27.0322
„ 978	H	+ 6.3.82	20.0788	+ 6.23.82	27.0315
„ 995	I	+ 2.38.37	20.0815	+ 2.49.79	27.0321
„ 1152	K	+ 0.56.77	20.0380	+ 0.53.09	27.0343
„ 1153	L	+ 5.25.91	20.0789	+ 5.59.05	27.0329
„ 777	M	+ 1.55.36	20.0820	+ 2.2.27	27.0369

GREENWICH NAVAL SCHOOL, REDUCED TO THE OBSERVATORY.

Arnold and Dent 820	N	+ 1.15.20	20.2083	+ 1.11.90	26.9722
„ 1017	O	— 0.22.70	20.2083	— 0.14.40	26.9722
„ 1045	P	+ 0.25.30	20.2083	+ 0.49.10	26.9722

DUBLIN OBSERVATORY.

A	$-20^{m}.18^{s}.15$	$21^{d}.9661$	$-20^{m}.8^{s}.72$	$25^{d}.0028$
B	— 25.19.22	21.9715	— 25.12.00	25.0076
C	— 22.6.00	21.9725	— 22.0.04	25.0062
D	— 24.53.50	21.9770	— 24.39.36	25.0090
E	— 21.44.66	21.9780	— 21.39.58	25.0076
F	— 25.6.92	21.9837	— 24.56.49	25 0104
G	— 25.27.30	21.9864	— 25.34.74	25.0125
H	— 19.11.95	21.9871	— 19.3 17	25.0083
I	— 22.39.63	21.9912	— 22.33.91	25.0118
K	— 24.25.35	21.9951	— 24.26.60	25.0139
L	— 19.46.04	21.9951	— 19.31.80	25.0111
M	— 23.23.22	22.0000	— 23.20.44	25.0146
N	— 24.6.83	22.0021	— 24.7.87	25.0163
O	— 25.41.70	22.0079	— 25.38.19	25.0180
P	— 24.49.39	22.0097	— 24.39.68	25.0183

The correction of the Dublin transit clock was on the 21st $= + 35^{s}.75$ by α Lyræ and α Aquarii, and its rate $= + 0^{s}.25$, using the places of the Nautical Almanac. It is confirmed by α Aquarii, Fomalhaut and α Pegasi on the 22nd.

The correction on the 24th $= + 36^{s}.53$ by α Cygni, α Aquarii, α Pegasi, and α Andromedæ.

ARMAGH OBSERVATORY.

A	— 21^{m}.29^{s}.10	22^{d}.9563	— 21^{m}.26^{s}.95	23^{d}.9724
B	— 26.31.61	22.9625	— 26.29.35	23.9770
C	— 23.18.33	22.9608	— 23.16.92	23.9761
D	— 26.3.46	22.9645	— 25.58.94	23.9786
E	— 22.57.05	22.9639	— 22.55.87	23.9778
F	— 26.17.89	22.9674	— 26.14.82	23.9815
G	— 26.44.10	22.9683	— 26.46.61	23.9826
H	— 20.23.35	22.9647	— 20.20.58	23.9787
I	— 23.52.59	22.9677	— 23.50.88	23.9819
K	— 25.39.57	22.9697	— 25.40.73	23.9843
L	— 20.55.21	22.9683	— 20.51.17	23.9816
M	— 24.36.72	22.9722	— 24.35.92	23.9857
N	— 25.20.74	22.9739	— 25.21.41	23.9876
O	— 26.53.93	22.9760	— 26.53.96	23.9904
P	— 25.59.82	22.9770	— 25.58.61	23.9904

The correction of the Armagh transit clock on September 21st was = — 30^{s}.45 by α and β Lyræ; ζ, γ, α and β Aquilæ; and α Cygni.

On Sept. 23rd, by the same stars, it = — 31^{s}.23, and the rate = — 0^{s}.38.

Hence I derive the following longitudes of Armagh; each being the mean of those coming and returning:

A	+ 26^{m}.35^{s}.39
B	36.32
C	35.46
D	35.03
E	34.69
F	36.17
G	35.74
H	35.56

I	35.69
K	35.12
L	35.28
M	35.06
N	34.67
O	35.12
P	35.99
Mean	26.35.44

The consistency of these results is very remarkable, the probable error of their mean being less than $0^s.1$, but its agreement with the longitude given by other means is not less striking.

From solar eclipses* of 1826 and 1836, and 19 occultations, 24 in all, I found

$$+ 26.35.58.$$

Three others were doubtful, as the star-paths were nearly tangents to the moon; but as the sum of the coefficients produced by the uncertainties of parallax and declination is nearly $= 0$, I add their mean with the weight of two $= 34^s.15$, and the occultation longitude is

$$+ 26^m. 35^s. 47.$$

The longitudes deduced from lunar transits give

Greenwich, 7 of first L.	26 36.26
„ 3 of second L.	32.04
	26.34.15
Dublin, 30 of first L.	35.16
„ 9 of second L.	42.49
	26.38.82
Cambridge, 11 of first L.	38.79
„ 3 of second L.	28.38
	26.33.58

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* The beginning in 1826; the beginning and end in 1836; and the beginning and end of the Annulus.

Königsberg, 8 of first L.	38.17
„ 4 of second L.	26.69
	26.32.43
Paris, 2 of first L.	42.06
„ 3 of second L.	32.42
	26.37.24

The differences are considerable, but I think the mean

26.35.64

must be very near the truth.

I have had few chronometric results previous to Mr. Dent's visit, and those obtained with my pocket-watch, Sharp, 1760, during my visits to London, &c. under unfavourable circumstances. They are:

Greenwich, 2 pair	26.35.44
Kensington, 3 do.	34.54
Edinburgh, 1 do.	36.04
	26.35.09

But the weights of these being much less than those of the results obtained with Mr. Dent's watches, can only be considered as depressing a little the mean of them.

On the whole, therefore, I am not inclined to change the quantity which some years since I gave to Mr. Stratford for insertion in the Nautical Almanac,

+ 26.35.50.

The differences between me and Dublin are:

A	+ $1^m.14^s.31$
B	14.84
C	14.56
D	14.63
E	14.30
F	14.57
G	14.39
H	14.30

I	14.91
K	14.18
L	14.13
M	14.46
N	13.73
O	13.95
P	14.55
Mean	+ 1.14.39

If each of these be subtracted from the corresponding longitude of Armagh, we obtain that of Dublin, such as would be given on the system of computation employed. But I have found by a direct comparison the longitude of Dublin :

A	+ $25^{m}.21^{s}.08$
B	21.48
C	20.90
D	20.40
E	20.39
F	21.60
G	21.35
H	21.26
I	20.78
K	20.94
L	21.15
M	20.60
N	20.94
O	21.17
P	21.44
Mean	+ 25.21.08

It is, I think, evident, that the original longitude of the Bishop of Cloyne, 25.21.00 is the true one. That illustrious astronomer had latterly increased this a second, probably induced by the result of lunar transits; but though I am sure he would not have done this without weighty reasons, yet I think the evidence of these chronometers would have been considered by him irresistible.

The geodetic difference of longitudes is, as I have already said, altogether unconnected with this inquiry, but in the ensuing summer I hope that we shall be able to lay before the Academy a determination of the differences between Dublin and Armagh, by means of Rocket signals, for which the Honourable Board of Ordnance have afforded us most ample means, though unfortunately too late in the autumn to be available this year. By the valuable aid of Lieutenant Larcom, I trust we shall be enabled to perform this interesting operation in the most satisfactory way; and by extending the same system to Mr. Cooper's Observatory at Markree, we shall have an arc of longitude measured in the most perfect manner, entirely across the island.

ARMAGH OBSERVATORY,
Nov. 9, 1838.